



CRC for Construction Innovation (2004) *CPW and 4d CAD : Technical Report 2002-056-C-TR03*. CRC for Construction Innovation, Brisbane

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## **CPW and 4d CAD**

**Technical Report 2002-056-C-TR03**

Fanny Boulaire and Gerardo Trinidad  
CSIRO Manufacturing and Infrastructure Technology  
PO Box 56 (Graham Road), Highett, Victoria 3190 Australia  
Email: [Gerardo.Trinidad@csiro.au](mailto:Gerardo.Trinidad@csiro.au)

**Research Program C**  
**Management and Delivery of Built Assets**

**Project 2002-056-C**  
**Construction Planning Workbench**

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Any enquiries should be directed to the CRC CI:  
[enquiries@construction-innovation.info](mailto:enquiries@construction-innovation.info).

## PREFACE

The Cooperative Research Centre for Construction Innovation (CRC CI) is a national research, development and implementation centre focused on the needs of the property, design, construction and facility management sectors. Established in 2001 and headquartered at Queensland University of Technology as an unincorporated joint venture under the Australian Government's Cooperative Research Program, the CRC CI is developing key technologies, tools and management systems to improve the effectiveness of the construction industry. The CRC CI is a seven-year project funded by a Commonwealth grant and industry, research and other government support. More than 150 researchers and an alliance of 19 leading partner organisations are involved in and support the activities of the CRC CI.

There are three research areas:

- Program A - *Business and Industry Development*
- Program B - *Sustainable Built Assets*
- Program C - *Delivery and Management of Built Assets*

Underpinning these research programs is an *Information Communication Technology* (ICT) Platform.

The Construction Planning Workbench project in the **Management and Delivery of Built Assets** core area is envisioned to demonstrate the feasibility of deriving draft construction schedules from IFC data generated from 3d CAD models. The project is also geared towards the investigation of methodologies in automatically linking construction schedules with 3d CAD models to produced visualisation and simulation of construction schedules.

The project is a collaborative effort between CSIRO Manufacturing and Infrastructure Technology and The School of Architecture and Built Environment at the University of Newcastle, together with the project's industry partners: Woods Bagot and John Holland. The members of the project team are:

Dr Guillermo Aranda-Mena	(Uni Newcastle)
Ms Fanny Boulaire	(CSIRO)
Mr John Crawford	(CSIRO)
Mr Robin Drogemuller	(CSIRO)
Dr Rod Gameson	(Uni Newcastle)
Mr Peter Hoskins	(Woods Bagot)
Ms Cheryl McNamara	(CSIRO)
Mr Willy Sher	(Uni Newcastle)
Dr Gerardo Trinidad	(CSIRO)
Mr Peter Ward	(Uni Newcastle)
Mr Nick Windmeyer	(John Holland)

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## INTRODUCTION

Construction process planning typically means scheduling and schedules in “Gantt Chart” format. This kind of a schedule is not a particularly good communication means for individuals having different background and being not necessarily familiar with formal scheduling outputs. It is essential to build trust between project parties and give the owners and users possibility to analyse and give feedback of the construction process plans.

The main reason for problems originating from project planning is due to the individual's misconception of reality. Thus, particularly in the case of multi-storey buildings one needs to have a good sense of 3D view in order to prepare the necessary plans. To increase the quality of the process plans better models and simulations of the construction process are needed. This is a one way to decrease the duration of the projects and same time keeping up the certainty that the schedule is realistic. Anecdotal evidence has shown that 4D CAD is indeed a good visualization and schedule review tool.

The AEC industry is experiencing an increase in the use of desktop 3D and 4D CAD (graphical illustration of 3D models with time as the 4th dimension) tools for project planning. This can be partially attributed to the decreasing cost of technology and increasing number of projects being designed in 3D CAD.

As a result, more companies are using or considering using 4D CAD for assisting in planning and reviewing construction plans for facilities. A 4D model combines 3D model with the appropriate scheduling data. Integration of the geometrical representation of the building together with scheduling data has been a topic for many research and development efforts [*Koo and Fischer (2000)*].

A construction project (e.g. buildings, roads and bridges) can be visualized in 3D CAD linked to the construction schedule, also known as 4D CAD. The Centre for Integrated Facility Engineering (CIFE) at Stanford University has performed extensive research in the area of 4D modelling. Several studies have focused on the use of 4D CAD on different building types. One such project is the Walt Disney Concert Hall project that is a US\$175 million, 2400-seat concert hall project located in Los Angeles, California [*Haymaker and Fischer (2001)*]. The complex project and tight spaces made coordination of construction activities a very high priority. The General Contractor saw the use of 4D visualization of the construction process as a tool for accomplishing four project objectives: schedule creation, schedule analysis, communication, and team building on this project.

There are several off-the-shelf 4D CAD computer applications that are readily available, such as Schedule Simulator™ from Bentley Systems, Common Points™ from Common Point Incorporated, fourDviz by Balfour Technologies, and SmartPlant® Review by Intergraph. These tools allow the planners to take 3D CAD model, separate the model into logical work packages, and then link the work packages, to a construction schedule. The planner can then, view and navigate the 4D CAD model and identify problem areas with the schedule or the design.

## Modelling in 4D

Developing such a 4D model posed a number of challenges. These challenges were related to the geometry, the schedule, and the linking of the geometry to the schedule. The challenges related to the geometry-involved inconsistencies in the 3D models obtained from the architect. These inconsistencies may result in extra work

while linking the schedule to the 3D model, as it was difficult to identify a particular 3D element and show the scope of work for its respective activity. The geometry issues also include cases where there is not enough data in the 3D model to enable 4D simulation and hence the 3D model must be modified to incorporate the necessary data. The other geometry related issue that can be encountered is in the level of detail of the 3D model. Sometimes the level of detail in the 3D model was too little to generate a 4D model and sometimes there was too much detail, which slowed down the computational processing of the 3D and 4D models.

Inconsistencies in the schedule can also present some problems. In some cases, there may be geometric elements that have no corresponding activity. Resolving these issues is a time and resource consuming process in 4D modelling. It is also possible that the schedule contained an activity with no associated geometric element.

### ***Modelling in 4D using Common Point***

Common Point 4D is a professional 4D Viewer and Producer for visually building and viewing 4D models. Common Point 4D includes many features to quickly build and view 4D models and update and edit 4D models.

In order to create a 4D model in Common Point, a VRML (Virtual Reality Modelling Language) file that describe the geometry of the 3D model and a text file for the schedule must be imported into Common Point.

The VRML file describes the geometry of the model. The geometry different elements constituting the building (i.e. slab, column, wall, beam) is described using a box or an indexed face set. A box describes the element dimensions in the three directions. The Indexed Face Set gives the coordinates of all the vertices and then describes each face using the number of the vertices.

The VRML file has to satisfy a few requirements in order to be compatible with Common Point. It can only have objects described as boxes or Indexed Face Set. Other shapes such as spheres, cones and others are not acceptable. Spaces are required before each "{" and "[". Although local coordinates for vertices are allowed in VRML, Common Point requires that global coordinates be used.

It is possible to import any comma-delimited or tab-delimited file in Common Point that has the following fields:

- Activity Description: Name for activity
- Unique ID: Some unique identifier so that updates of the schedule are possible
- Start field
- End field

The input file can be generated from Project Management software Primavera and Microsoft Project. It is also possible to directly create a text file with the required information.

The detail of the 3D building model should match the detail in the construction schedule. For example, if the schedule has activities such as "Pour concrete for slab in floor 1" then the 3D building model should have an element or group of elements representing the slab on the first floor. If the schedule has an activity "Pour concrete for slab in floor 1 - section 1" then the 3D building model should have elements representing the individual sections.

## An Example in Common Point

Consider a simplistic example of a building as shown in Figure 1. It is a 2-storey reinforced concrete building with six-pad footing as foundation. The building consists of beams, columns, footings, slabs and walls. Figure 2 illustrates various stages of the construction of the simple building. The flow of information is summarised in Figure 3.

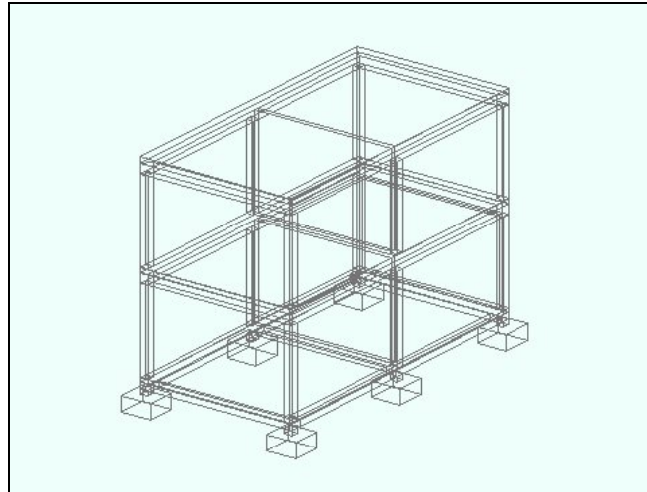


Figure 1: Wire-frame image of a very simple building

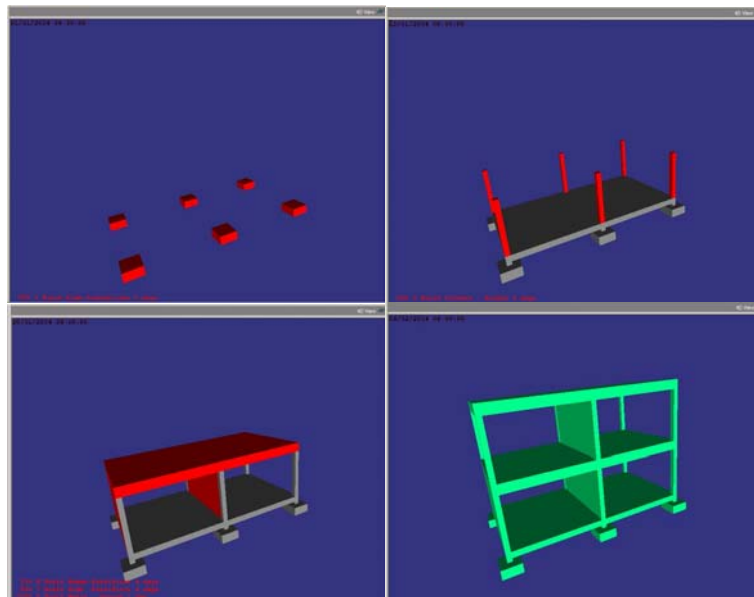


Figure 2: Visualisation of the construction of the simple building in Figure 1

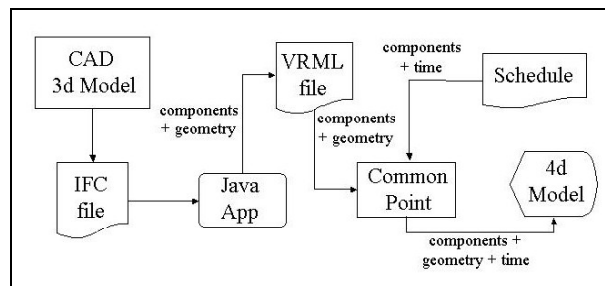


Figure 3: Flow of information in 4d visualisation in Common Point



## ***Modelling in 4D using Bentley Navigator***

Bentley Navigator is an application for visualizing and navigating graphical and non-graphical facility information. It displays 3D models for interactive navigation and review or for querying of information from operations, scheduling, purchasing and other external systems. A simple interface broadens information access to those without CAD expertise.

It can visually simulate the construction process by integrating detailed 3D models with critical scheduling and planning information. Provide project managers with actual versus planned construction comparisons, analysis of construction issues, improved design and procurement strategies, and exploration of alternative dispute resolutions.

Bentley Navigator is a real-time 3D visualization program that enables to view and interact with JSpace models and related data. JSpace is the object-oriented technology developed by Bentley Systems, Inc. The JSpace object model files can be created and edited using the JSpace Class Editor.

JSpace has interfaces with CAD systems, such as MicroStation and AutoCAD, and with database systems, such as Microsoft Access, Oracle, and SQL Server.

A DGN file created by a CAD system can be exported to a JSM file using the Interference Manager in MicroStation TriForma.

The schedule is also a JSM file that contains information from an external Primavera schedule or an external Microsoft (MS) Project schedule. To create a schedule based on an external MS Project schedule, data must be imported from an existing MPP file into a JSM schedule model. If the external MS Project schedule is modified, JSM schedule model must be updated.

As in Common Point, a graphic model object must be linked to a schedule activity object in order to perform a 4d simulation, Figure 4 shows a sequence of construction steps in the 4d visualisation done using Bentley Navigator.

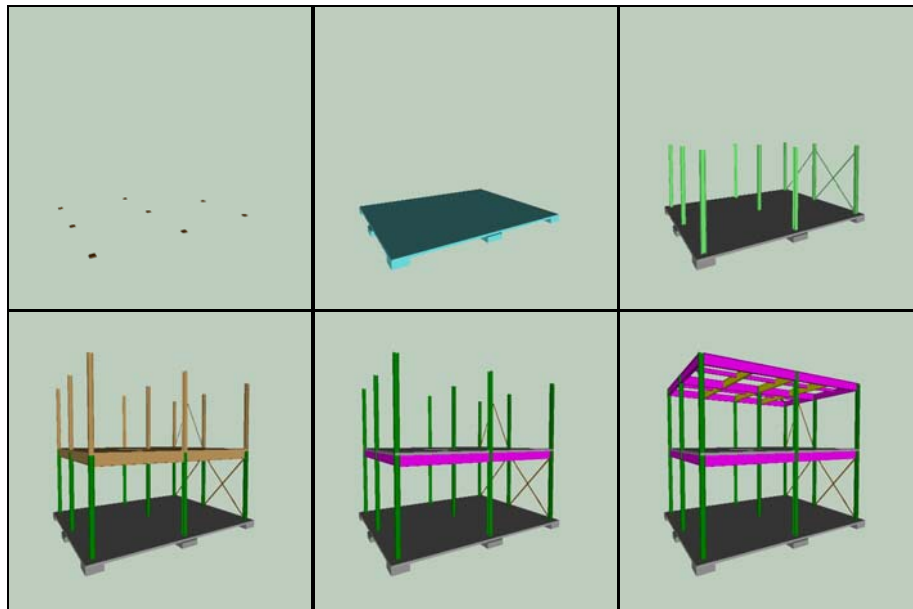


Figure 4: 4d visualisation of a construction sequence in Bentley Navigator

## Modelling in 4d using ArchiCAD

A major addition to ArchiCAD comes in the form of a task-based construction simulation module. By linking to Microsoft Project, ArchiCAD can generate still images of building status by date or produce animations of construction over time. Construction Simulation hierarchical menu allows users to simulate the construction process with ArchiCAD 3D model by associating construction elements to a task list. This list can be created within ArchiCAD or imported from a Microsoft Project database.

The Construction Simulation dialog box (see Figure 5) includes the following fields: Tasks, Type, Progress, Start Date and Finish Date. Fields can be edited by double-clicking in them. Clicking on any header will sort the task list by that key.

The Tasks, Start Date and Finish Date fields are imported from MS Project. The Progress field is automatically filled by ArchiCAD to conform to the Current Date defined at the bottom of the dialog box. Otherwise, this field is not editable.

Types are defined manually with a pop-up menu listing task types. There are five types of construction tasks:

- **Build:** Elements do not exist when simulation starts. They are constructed during the task and then remain there.
- **Demolish:** Elements are present on the site when simulation starts. They are removed during the task.
- **Restoration:** Elements that are present both at the start and the end of the task. Work is performed on them during the task.
- **Freeze:** Elements that are present both at the start and the end of the task, but no work is performed on them.
- **Temporary:** Elements that are not present when simulation starts. They are constructed during the task and are removed at the end of the task.

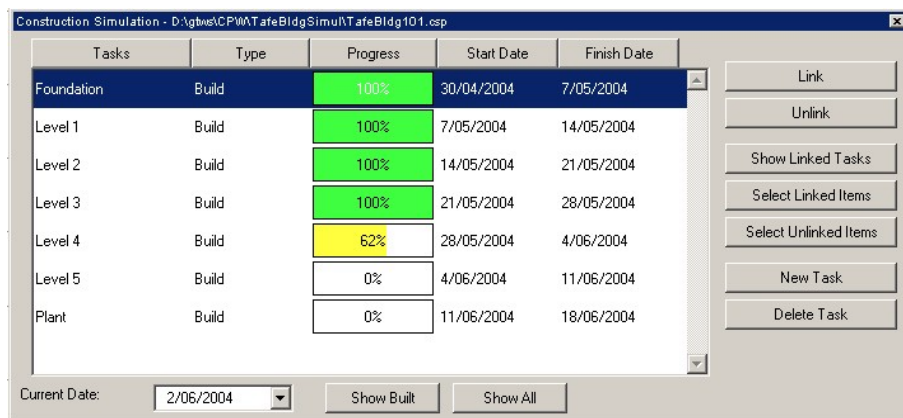


Figure 5: Construction Simulation dialog box in ArchiCAD 7.0

With the Construction Simulation tool ArchiCAD users can assign time parameters to each element of the Virtual Building and visualize the status at any given time, even create an animation. Figure 6 illustrates the simulated stages of the construction of a 5-storey building.

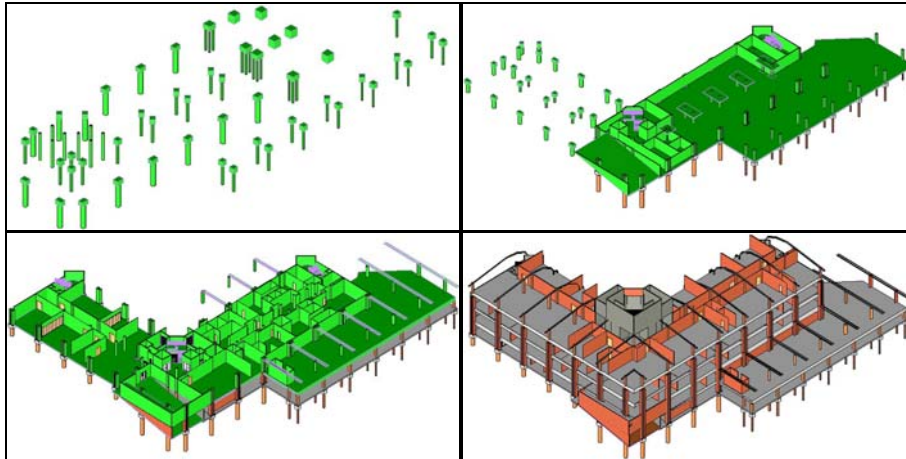


Figure 6: Stages in the simulated construction of a building in ArchiCAD 7.0

## OTHER APPROACHES IN 4D CAD

Several documented studies have shown that 4D CAD is indeed a good visualization and schedule review tool as discussed in the previous section. However, the scope of such tools is limited to schedule review and these programs require a completed schedule for implementation. In the case of large and complex facilities, use of these tools for schedule review is time consuming due to the effort required in generating the construction schedule in the first instance. Further, these tools do not allow an interactive environment for construction planning.

Considerable advancements have been made in the graphical display technology and the interface between computers and human. Through the use of virtual reality and immersive projection display technology, planners can now interact with very realistic views of the building. Unfortunately, the current use of virtual reality and immersive projection display in the construction industry has been limited to research. For example, virtual reality in construction has been used to develop and visualize project designs [Haymaker and Fischer (2001)], and visualizing construction operations [Kamat and Martinez (2001)].

The following sections introduce possible approaches in using virtual reality and augmented reality with examples of developed tools, as well as some advantages of using them to 4D CAD applications.

### **CAVE Automatic Virtual Environment**

CAVE is an acronym for the CAVE Automatic Virtual Environment, a room-sized advanced visualization tool that combines high-resolution, stereoscopic projection and 3-D computer graphics to create the illusion of complete sense of presence in a virtual environment.

CAVE was developed by Electronic Visualization Laboratory, University of Illinois at Chicago, and first demonstrated at SIGGRAPH in 1992.

CAVE was the first virtual reality technology in the world to allow multiple users to immerse themselves fully in the same virtual environment at the same time. Figure 7 shows CAVE and multiple users immersed in this virtual environment.

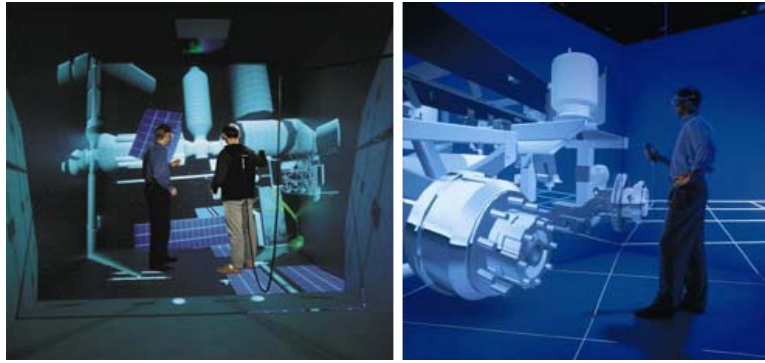


Figure 7: CAVE - Immersion of multiple users in the virtual environment

The Immersive Virtual Environment is created by three rear-projected images on walls and one front projected image on floor. This added to the use of shutter glasses to get the stereoscopic view and six DOF head tracking system to adjust the perspective creates the virtual environment. A number of features are available to enhance the users experience such as gesture recognition, voice recognition and collision detection that improve the interaction with the image.

The CAVE solution is of a great use for many different applications including manufacturing and design reviews. Very little research has been done on the use of Immersive Virtual Reality as a tool for construction planning but some benefits of using Immersive Virtual Environments for project planning have been identified.

Indeed, experiments using CAVE showed that it is a good review tool, as constructability issues could be identified more easily than when using desktop 2D. Whereas the planning had been reviewed on a 2D desktop using a 4D representation, wrong sequencing between objects and space-time conflicts persisted. Moreover, activities that could be done in parallel were identified which reduced noticeably the construction planning duration.

This Immersive Virtual Environment also showed quality for communication, which is important when different stakeholders have to communicate to satisfy each other goals. By being able to host multi-users, the different participants could interact on the same basis and communicate better their ideas.

### **Augmented Reality for face-to-face collaboration**

Another approach for visualizing construction planning can be done with Augmented Reality. While Virtual Environment involves being immersed in a non-real environment, Augmented Reality (AR) involves the overlay of virtual graphics and audio on reality.

Communication is very important while designing or reviewing the planning. When using the usual 2D desktop, people crowding around it are less able to refer to real object or use natural communication behaviors.

By using Augmented Reality for face-to-face collaboration, better communication is possible. Hence, Augmented Reality can be used to enhance a shared physical workspace and create an interface for 3D representations. Figure 8 shows one of the first interfaces of AR for face-to-face collaboration [Schmalstieg et. al. (1996)]. Through head-mounted displays, users can collaboratively view 3D virtual objects superimposed on the real world. They can thus discuss on some issues on a particular element in the model and simply interact with the others by pointing at it to ensure that everyone is speaking of the same thing. Multiple users can see each other and cooperate in a natural way, as they would in a physical environment. This tool also ensures the independence of the user as he controls his own independent viewpoint.

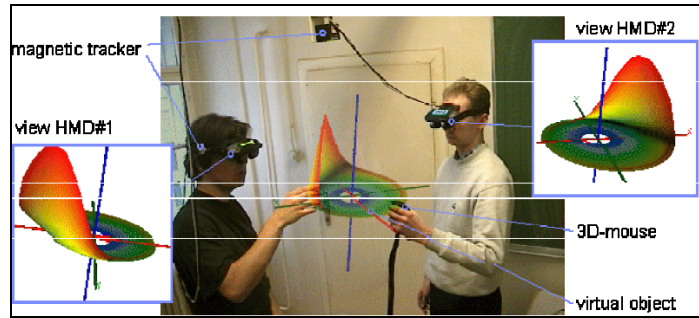


Figure 8: Example of augmented reality for face-to-face collaboration

Augmented Reality can be of great interest for designing and reviewing construction plans. One can imagine the model being a storey of a building, for example, and the different collaborators of the project looking at the simulation of construction of the building. They could interact with each other and discuss some issues on the same model. An advantage of this augmented reality environment is the size of the needed workspace, which can be fairly small.

## GENERATING VRML FROM IFC

The use of Common Point as a tool for the generation of a 4D model implies importing a VRML (Virtual Reality Modelling Language) file for the visualization of the building and its construction as it evolves in time.

Having the project described using the IFC (Industry Foundation Classes), the generation of a VRML file with the information stored in an IFC file is needed.

Hence, a tool was created to convert the relevant information for the visualization, from IFC to VRML. This application has been written in JAVA and is composed of 3 packages corresponding to the different phases in the information flow: Ifc2x package, VRML and driver package.

### IFC to VRML

In order to store the information contained in the IFC file, EDM Database was used. This object-oriented database allows importing IFC files with their schema describing the structure of the model. The schema used here is the ifc2x one.

Then a JAVA program makes a link to this database to extract the information needed for the generation of the VRML file. This information is then computed and a VRML file is created. Figure 7 shows this information flow from the IFC file to the creation of the VRML one.

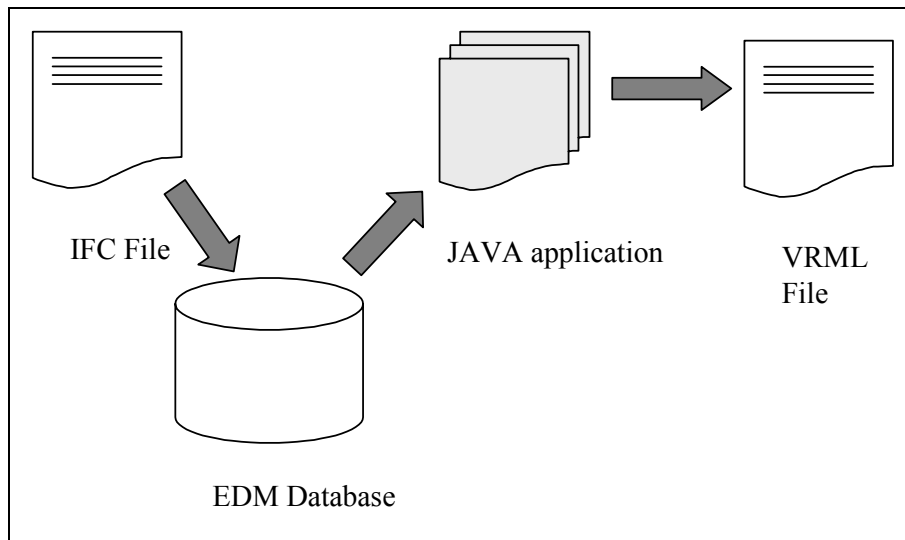


Figure 7: Information flow for the generation of a VRML file from an IFC file

The JAVA application is thus composed of three packages:

- A driver package, for the user to choose the database in which the IFC model is stored and open it
- A VRML package that organizes which data are needed for the generation of the 3D visualization and writes them in the VRML file
- An ifc2x package, that gets the information from the database and feeds it to the VRML package

## Java Packages

### Driver Package

The driver package contains the main method of the program. It creates a user interface (UI) as shown in Figure 6, that get the database location and name, its password, the name of the IFC model and the repository in which it is, and then the location and name for the VRML file.

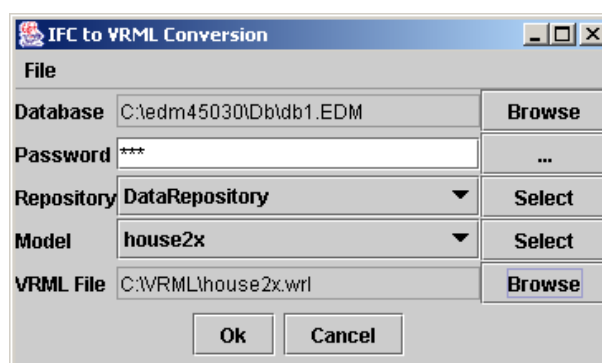


Figure 6: User interface for IFC to VRML conversion

Once the user enters all these fields, the program opens the database specified and gets the instance for the connection. It then calls the VRML and ifc2x packages for the extraction and computing of the information.

### VRML package

The VRML package is the one that creates the VRML file. The 3D world is described in this file according to the VRML standard format and the information from the IFC



file. The first line required in a VRML file is “#VRML V2.0 utf8” that allows the VRML browser to recognize the file as being VRML code and thus parses it correctly.

The objects in a VRML file are called nodes and are arranged hierarchically in order to affect one another in different manners. There are basically three types of nodes:

- Shape nodes, which describe the geometry and appearance
- Property nodes, which modify the geometry
- Grouping nodes, which allow groups of objects to be modified as one object

Since the IFC data have a hierarchy between the different parts of a project, this hierarchy was respected through the grouping nodes in VRML. Hence groups were defined depending on how many sites were in the project, how many buildings in each site, how many stories in each building and elements on these stories.

Then in order to describe the elements within each group the shape nodes were used. These nodes describe the geometry of the element (box, sphere, cone...) as well as its appearance (colour, shininess, transparency...). The geometry characteristics (type of object, size, coordinates...) of each structural element of the project were given by calling geometry methods from the ifc2x package.

As described previously, Common Point does not handle all the geometry description that VRML does. Thus some modifications had to be done before writing the VRML file. For example, even if coordinates of the vertices of an element can be given in a local coordinate system and then transformed in the global one in VRML code, Common Point requires them to be given directly in the global coordinates system. Hence methods in this package do the transformation first and then give the points in the global coordinate system. Moreover, some geometry properties are not either handled such as “Extrusion”, which takes a base of a solid, a direction and length of extrusion and thus describes the whole object. This would have been useful as IFC has the same representation, but in this case also, the calculation of the coordinates of the edges had to be calculated and then written in the VRML file.

After the geometry, the appearance of the objects had then to be described. The appearance is to render the object as wanted in the visualization window. Hence parameters differ depending on the colour and the aspect the material has, more or less shiny, transparent... At this stage, we have decided that all the elements constituting the building would have the same appearance in order to simplify the code.

Given the hierarchy between elements, and the geometrical and appearance properties of each element, the file could then be written according to the VRML code.

## **ifc2x package**

The ifc2x package is the link between the driver package and the VRML one. Hence, it reaches the information contained in the ifc2x model, from the database and then gives it to the VRML package for further computation.

This package is constituted of many classes that describe entities as those defined in the IFC2x schema. Hence each class represents an entity and has the same attributes as in the IFC schema. Thanks to that, it is possible to follow the way entities are described and thus reach all the relevant information for the application. As an example, it is possible to get the instance of a slab as described in the model, and gets its attributes such as its geometry, location in global coordinate system, material ... All of this is got from an initial instance and following the structure to get the other ones that lead to the relevant data needed for the problem.

Hence, thanks to the communication between those 3 packages, it is possible to get the information contained in an IFC file and writes them in a VRML file.

This VRML converter supports the conversion of the structural elements of the building: walls, slabs, beams and columns. Not all the geometry is supported at present, only the most common ones (bounding box, extruded areas, clippings), which faces can be described as polygons. Hence, circles and curves are not yet supported as Common Point does not handle them, but approximating them by segments of lines still can represent them.

## **CONCLUDING REMARKS**

This technical report describes the relationship between the CPW initiative and 4d CAD research and development efforts in Europe and America.

This technical report describes how results from CPW can be used in conjunction with 4d CAD visualisation and simulation.



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